A NORMAL INCIDENCE X-RAY TELESCOPE (NIXT)

SOUNDING ROCKET PAYLOAD

Grant NAGW-397

Final Report

For the Period 1 November 1982 through 31 January 1989

Principal Investigator
Dr. Leon Golub

May 1989

Prepared for:

National Aeronautics and Space Administration
Headquarters
Washington, D.C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics

The NASA Technical Officer for this grant is Dr. Sharad Kane, Code EZ, National Aeronautics and Space Administration, Headquarters, Washington, D.C. 20546.

NIXT/HRX Final Report

Table of Contents

"High Resolution Imaging Detector for Use with a Soft X-ray Telescope", L. Golub and K. Kalata, Proc. SPIE 733, 533 (1987).

"Design Considerations for Soft X-ray Television Imaging Detectors", K. Kalata and L. Golub, Proc. SPIE 982, 64 (1988).

"A High Resolution Phosphor Screen for XUV Detectors", B. Sams, L. Golub and K. Kalata, J. Phys. E: Sci. Instrum. 21, 302 (1988).

0. Introduction

This Final Report describes the work which has been performed during the period 30 April 1987 through 31 January 1989 under NASA Grant NAGW-397, "A Normal Incidence X-ray Telescope". This work was funded by an interagency transfer originating with AFGL (PHS), the purpose of which was to initiate development of a soft x-ray imaging detector to be used in combination with multilayer-coated x-ray and XUV optics.

1. The High Resolution X-ray (HRX) Detector Program

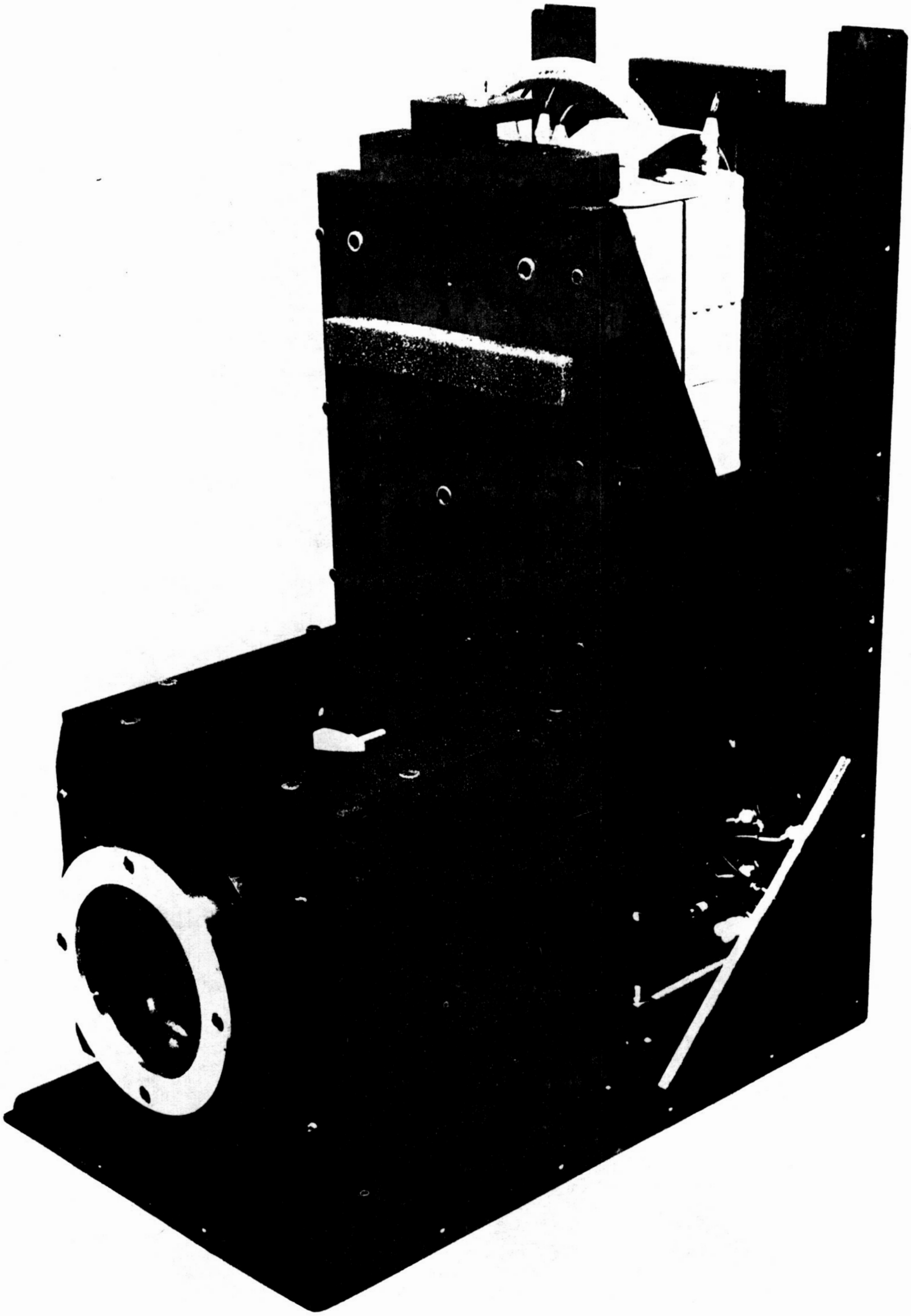
Television sensors such as CCD's and vidicons can be coupled to convertors and image intensifiers to obtain two-dimensional imaging detectors with large active areas, high flux capabilities, high quantum efficiency, high time resolution and large dynamic range. There is available a wide range of sensors, convertors and image intensifiers. One technique is to use a thinned, backside illuminated, cooled, slow-scanned CCD as a direct sensor. This technique is useful for x-rays with energies between about 0.1 and 10 keV; sensitivity at lower energies in the XUV can be obtained by the use of addition specialized techniques.

These devices work well when the CCD pixel size matches the desired focal plane resolution and when the illumination is not too high, since exposure to XUV radiation can produce damage. The technique which we have been pursuing is to use a thin phosphor to convert the x-rays into visible light, which can be directly detected with a CCD or vidicon, or which can be further amplified with an image intensifier before being read out. Fiber optics tapers can also be used to match the focal plane pixel size, whichcan be as small is 2.5 μ, to the pixel size of the readout device.

In our laboratory and flight programs we have constructed multiple copies of a general purpose set of electronics which control the camera, signal processing and data acquisition. The camera heads have used SIT and vidicon tubes, and Fairchild and Videk CCD cameras, and they have active areas ranging from 10 to 80 mm diameter (Golub and Kalata 1986; Kalata 1985; Kalata, Murray and Chappell 1984). A typical system consists of a phosphor convertor (Sams, Golub and Kalata 1988), an

Figure 1

Intensified CCD camera for laboratory use consisting of 75 mm image intensifier with phosphor input, coupled via fiber optics and lens combination to a Videk Megaplus CCD camera.



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

image intensifier, a fiber optics coupler, a CCD readout, and a set of camera, signal processing and memory electronics. Our system using a 75 mm bialkali photocathode MCP intensifier, fiber optic reducer and lens coupling to a Videk 1320X1035 CCD is shown in figure 1.

1.a. Prototype Detector Test Program

Our initial rocket detector prototype camera utilized a commercial CCD camera operating at visible light wavelengths. The optics for this system were a 1 meter focal length telephoto lens, designed at IBM and built at SAO, with a Daystar Research Grade H_α filter built for this program by Del Woods. Because our x-ray cameras operate by converting the x-ray photons into visible light, it is possible to test prototype systems in the visible and then add a phosphor convertor as the last step in constructing the x-ray system. Therefore we tested the prototype camera at H_α in order to establish a baseline operational procedure upon which to build.

The camera was used in our first flight and performed perfectly, providing pointing and stability information in real time during the flight. Images were transmitted to the ground and recorded on VHS format video recorders. Coalignment with the NIXT x-ray telescope was carried out prior to launch and control axes of the SPARCS system were established with respect to the real-time video image in order to correct for pointing errors if necessary; this was not needed in our first flight but was crucial to the success of our second flight as described below (§2.a).

1.b. Laboratory X-ray System

The HRX detector consists of several subsystems: the detector assembly, or camera head; the scan control and readout electronics; the image acquisition and processing electronics; and the image storage and display electronics. Portions of this system have been configured for flight, as described above, and several copies of the entire system have been constructed for use in the laboratory.

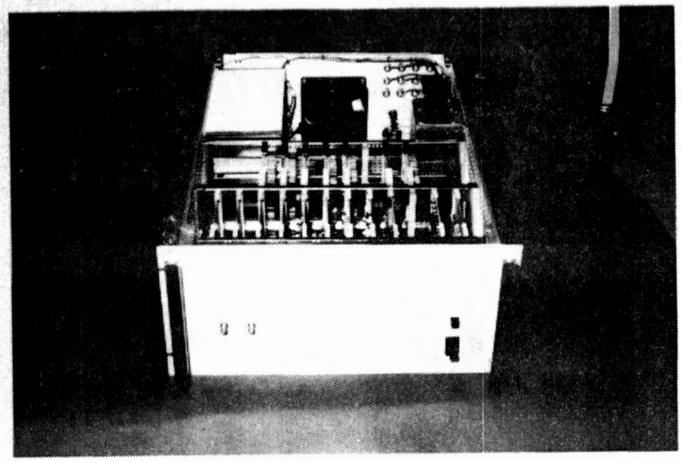
The basic lab system consists of three separate electronics modules, shown if Figure 2a,b,c: 1. camera electronics, 2. signal processing electronics, and 3. high-speed memory system; a block

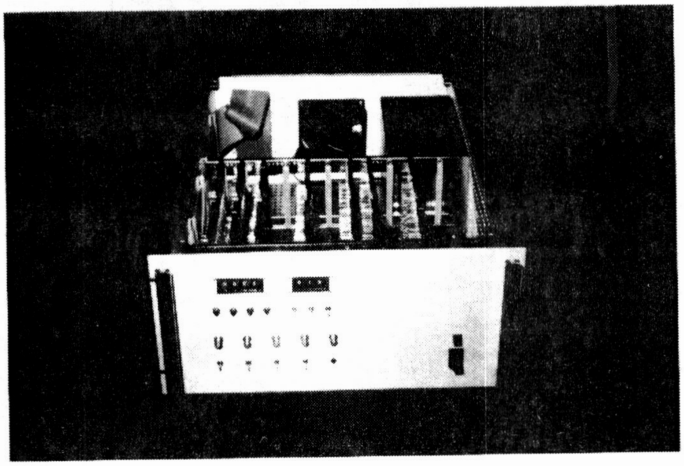
Figures 2a, b, c

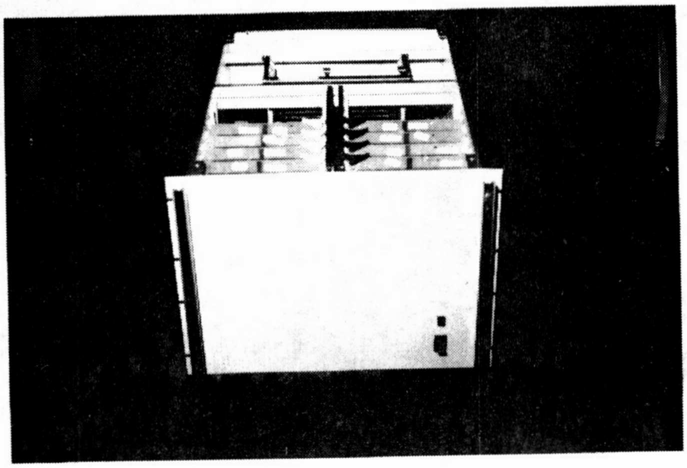
(a) Scan control,

(b) Image processing, and

(c) Dedicated high-speed memory







ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Figure 2d

(d) Functional block diagram of the electronics

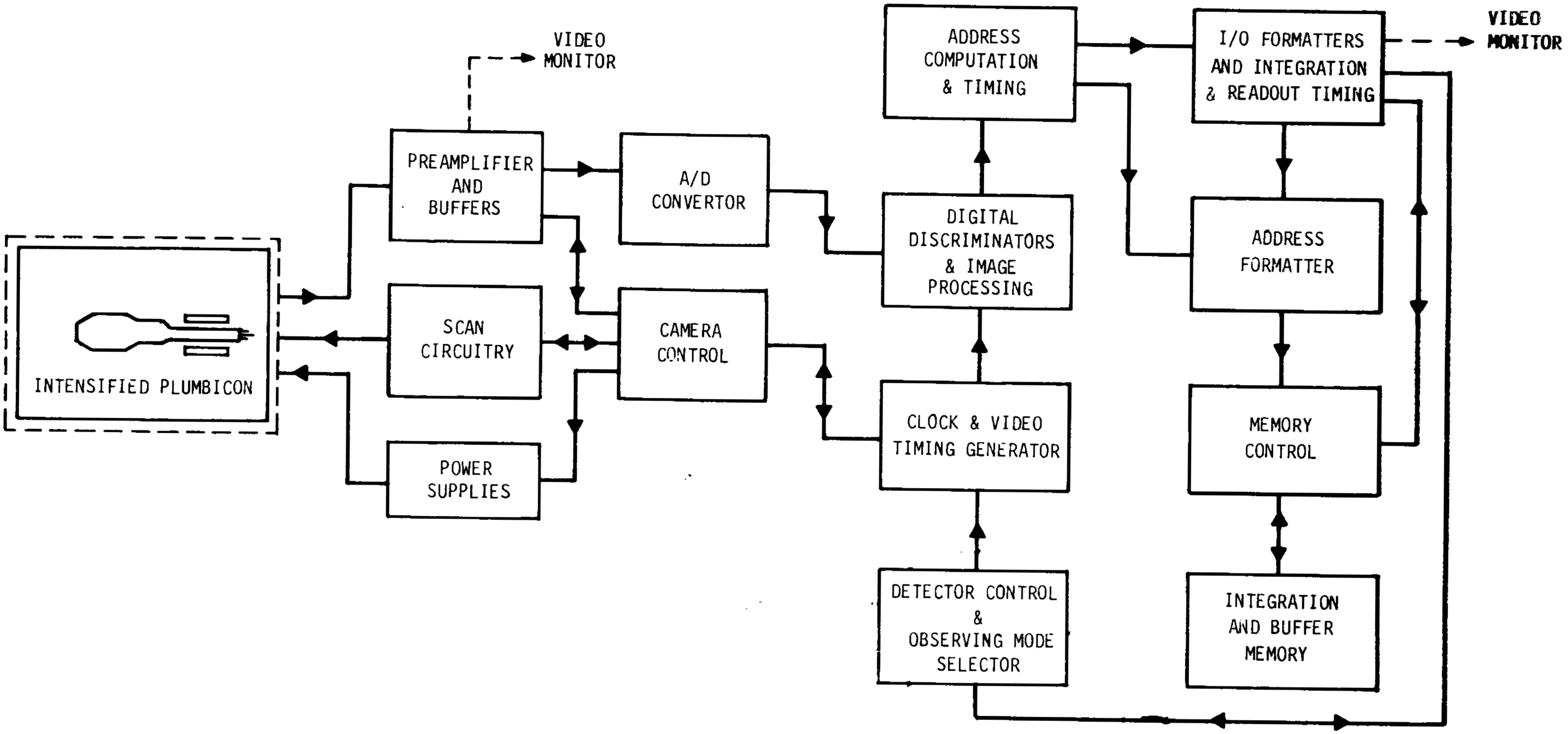

INTENSIFIED PLUMBICON
VIDEO MONITOR
PREAMPLIFIER AND BUFFERS
SCAN CIRCUITRY
POWER SUPPLIES
A/D CONVERTOR
CAMERA CONTROL
ADDRESS COMPUTATION & TIMING
DIGITAL DISCRIMINATORS & IMAGE PROCESSING
CLOCK & VIDEO TIMING GENERATOR
DETECTOR CONTROL & OBSERVING MODE SELECTOR
I/O FORMATTERS AND INTEGRATION & READOUT TIMING
VIDEO MONITOR
ADDRESS FORMATTER
MEMORY CONTROL
INTEGRATION AND BUFFER MEMORY

diagram showing the functional layout of this system is shown in Figure 2d.

The camera electronics generate the sweep currents and tube voltages needed to scan the TV tube, as well as clock signals for a CCD array, and they also process and digitize the analog video signal. The scan format, i.e., the length and duration of each scan line and the number of scan lines per frame are set under computer control. A video amplifier generates video and sync signals which are digitized by A/D convertors and also displayed on a video monitor.

The clock and timing electronics generate the basic clock frequencies, timing pulses and gating signals that control the operation of the camera electronics and the image processing logic. Under computer control fast or slow scan operation or single frame integration and readout may be selected; a grated rectangular window with any height or width from 1 to 4094 pixels can be placed around a region of interest in the field. Status and timing signals are made available to the control computer so that detector operation can be controlled on a line-by-line basis in real time if needed. A loadable matrix of lower level discriminator settings permits independent setting of discriminator thresholds at each point.

The image can either be displayed directly or integrated in a large, high-speed memory system. The memory system accents the data word from the detector electronics and adds or subtracts it to the sum accumulated in that address on the previous frames. In the A/D mode this occurs every pixel; in the photon counting mode the appropriate memory location is incremented when an event is detected. In order to accommodate data rates as high as 10 MHz, up to 8 sets of memory cards can be sequentially multiplexed. A memory word of 8, 16, or 24 bits can be programmed into memory. The memory system cimultaneously displays the accumulated image both during and after integration using a video or X-Y monitor.

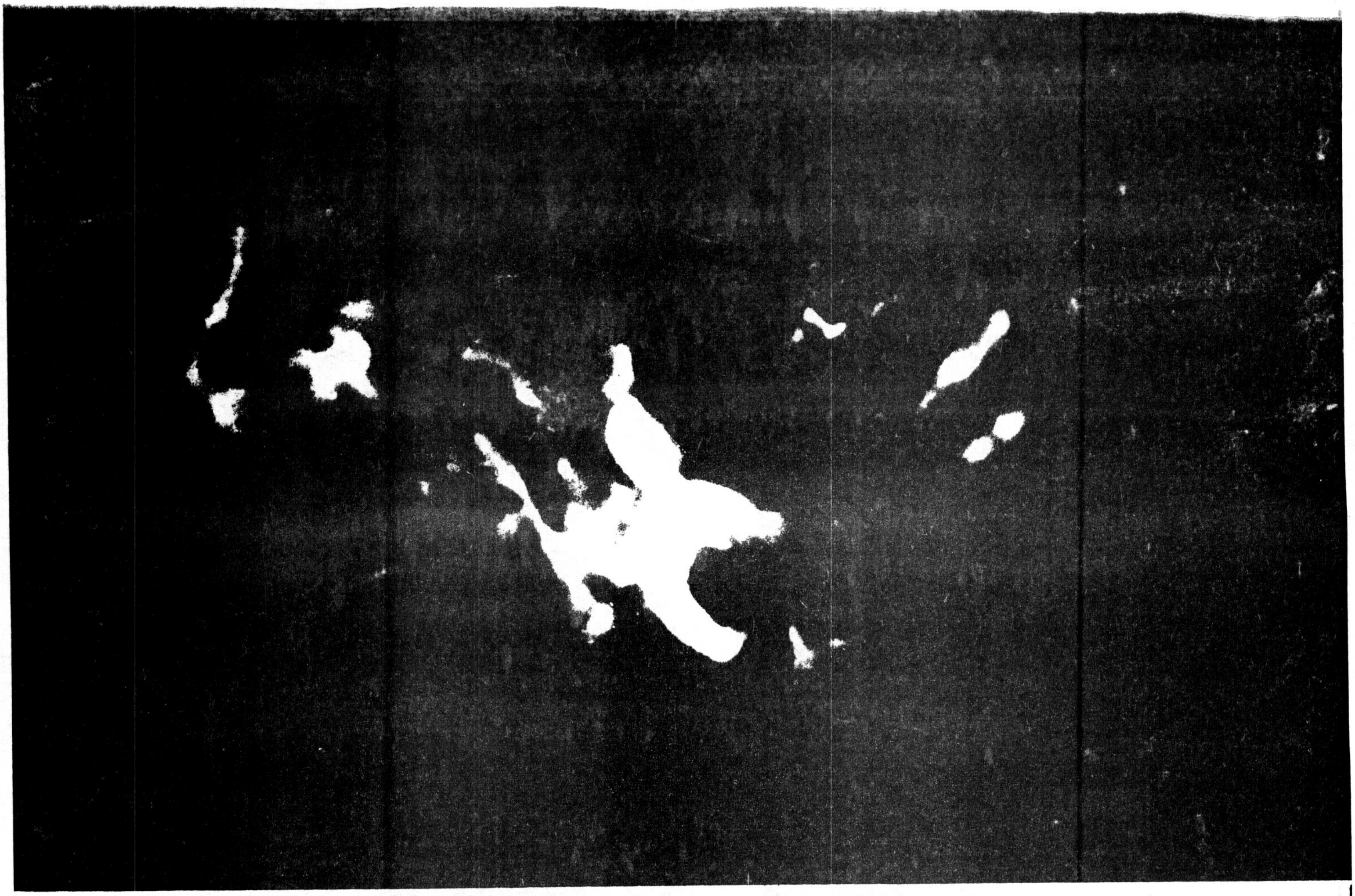
In operation on the ground, an image is accumulated in the detector memory, displayed on a video or X-Y monitor, and read into the computer. If the image size is smaller than the memory capacity, multiple integrations can be stored in memory before being read out. The detector electronics can be programmed to integrate an arbitrary number of frames in one portion of memory and then automatically begin another integration in the next portion of memory, until all of memory is filled or the procedure is reset by the computer. Because the memory is dual ported, one portion of memory can be read out while another is being integrated, although the transfer of an image to the computer will take many frame times.

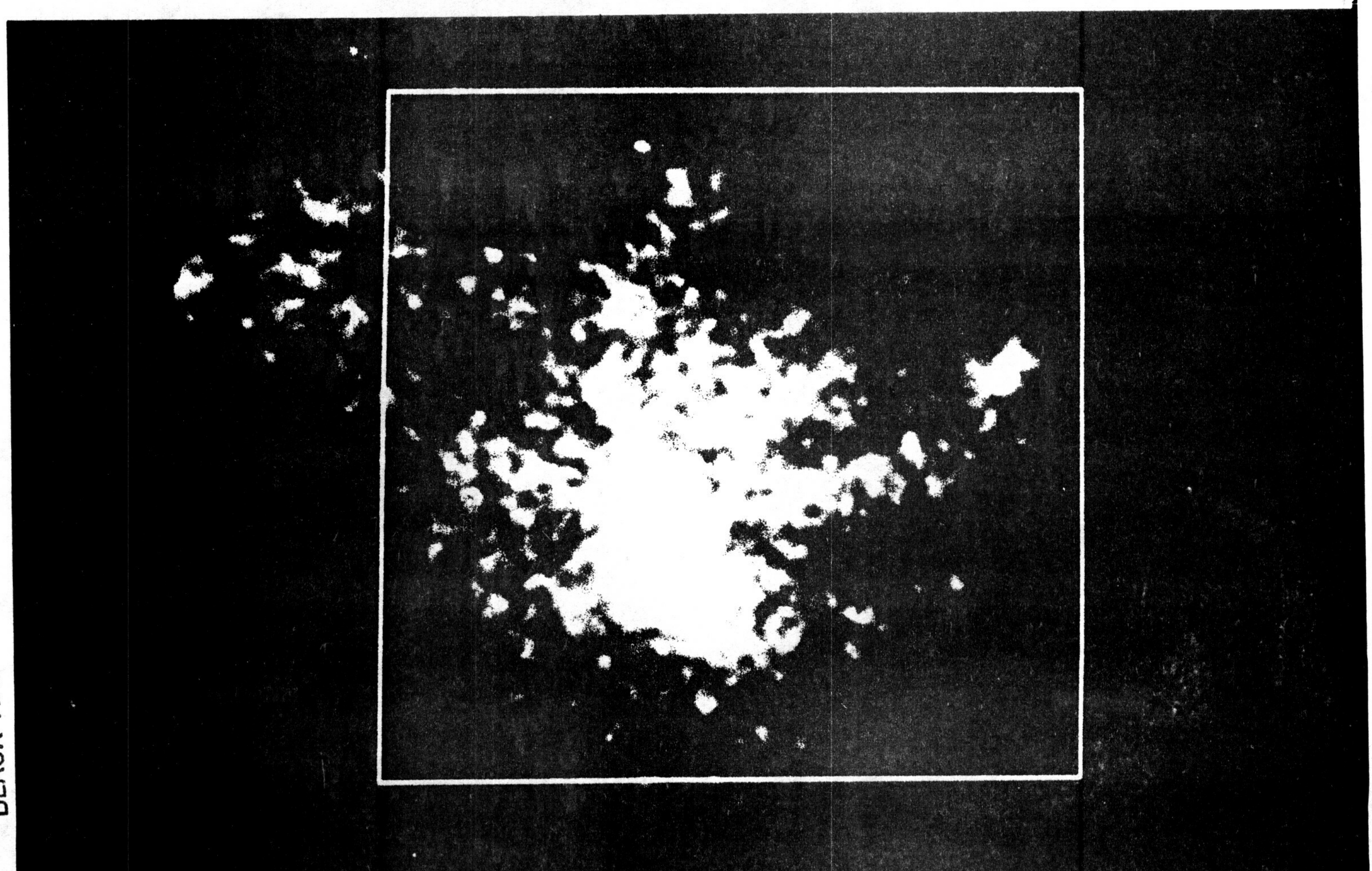
The digitized images are transferred from the high resolution CCD camera to our group's data analysis system via the data acquisition and image processing electronics built by us as part of this program. Data are stored in a dedicated µVax II supporting the ANA interactive data manipulation language (provided by R. Shine of LPARL), with a Calcomp 1280X1024 image display system. In addition to the NIXT x-ray data and the SMM XRP and UVSP arrays, we have also collected both longitudinal and vector magnetograms, He I λ10830 area scans around the flare site, and patrol H_α in digital form. These data sets have all been coaligned, using white light or continuum images in which sunspots are visible as the common reference. An outline box 100 arcsec on a side has been placed on each image, and the images were then photographed using a 35 mm camera for hardcopy prints.

A sample of several such images is shown in figure 3. The NIXT x-ray image shown is a summation of the two useable frames obtained during the flight. These two frames were a 100sec and a 30 sec exposure, taken about two minutes apart, and to the best of our ability to determine there are no significant differences in the appearance of the flare region between the two exposures. Since the signal-to-noise ratio in the dseparate images is low, we have summed them. The digitized images were coaligned in the computer by cross-correlation, and then smoothed to eliminate most of the random high frequency spatial noise. Unfortunately, some of the lower frequency noise remains, and gives the appearance of a pattern similar to the network; this noise pattern appears as faint filamentary structure visible in several portions of the image. We emphasize that this is not real and we do not believe that any chromospheric structure is een in these images.

Figure 3

(ToP)	Ground-based H-alpha photograph of a two-ribbon flare.
(Bottom)	Corresponding x-ray image of the flaring corona above the H-alpha region.





NIXT Flight, 17:46 UT 06/23/88, 63.5 A.

2. Flight Programs

2.a. H_α/Vidicon System

On our June 1988 rocket flight we incorporated an advanced prototype detector system, in which an high resolution hetero-junction Vidicon tube was used as the readout device for the H_α telescope. The camera electronics for this tube were built in-house and included in the flight electronics. A photograph of the telescope/camera assembly is shown in Figure 4.

The system was designed for interactive control during the flight. In particular, we incorporated the ability to change scan format during the flight by ground command. A block diagram showing the operation of the command link and the transmission flow path of the data images is shown in Figure 5. The standard image format, pre-programmed into the camera control electronics at the start of the flight, was a standard RS-170 television image (525 lines resolution, 30 frames per second). During flight we switched to a high resolution mode, incorporating twice the number of scan lines at half the frame rate. This format was chosen in order to be compatible with standard VHS recorders, which will lock onto this type of signal and record the broadcast image with only minor gaps in the image during inter-head transfer.

Performance of the detector system in the June 1988 flight was 100% satisfactory. The camera head operated exactly as designed, the broadcast quality of the image throughout the flight was noise-free and the data were successfully recorded using both VHS and Super-VHS machines. The availability of this image in real time during the flight was crucial, because it was our only means for detecting and correcting a mis-pointing of the payload due to partial failure of the SPARCS system.

2.b. Future Developments

We are currently in the process of reconfiguring the telescope for its next launch, scheduled for the Summer of 1989. There will be two major new changes in the payload for this flight:

Figure 4

Rocket-borne H-alpha telescope with Vidicon readout.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

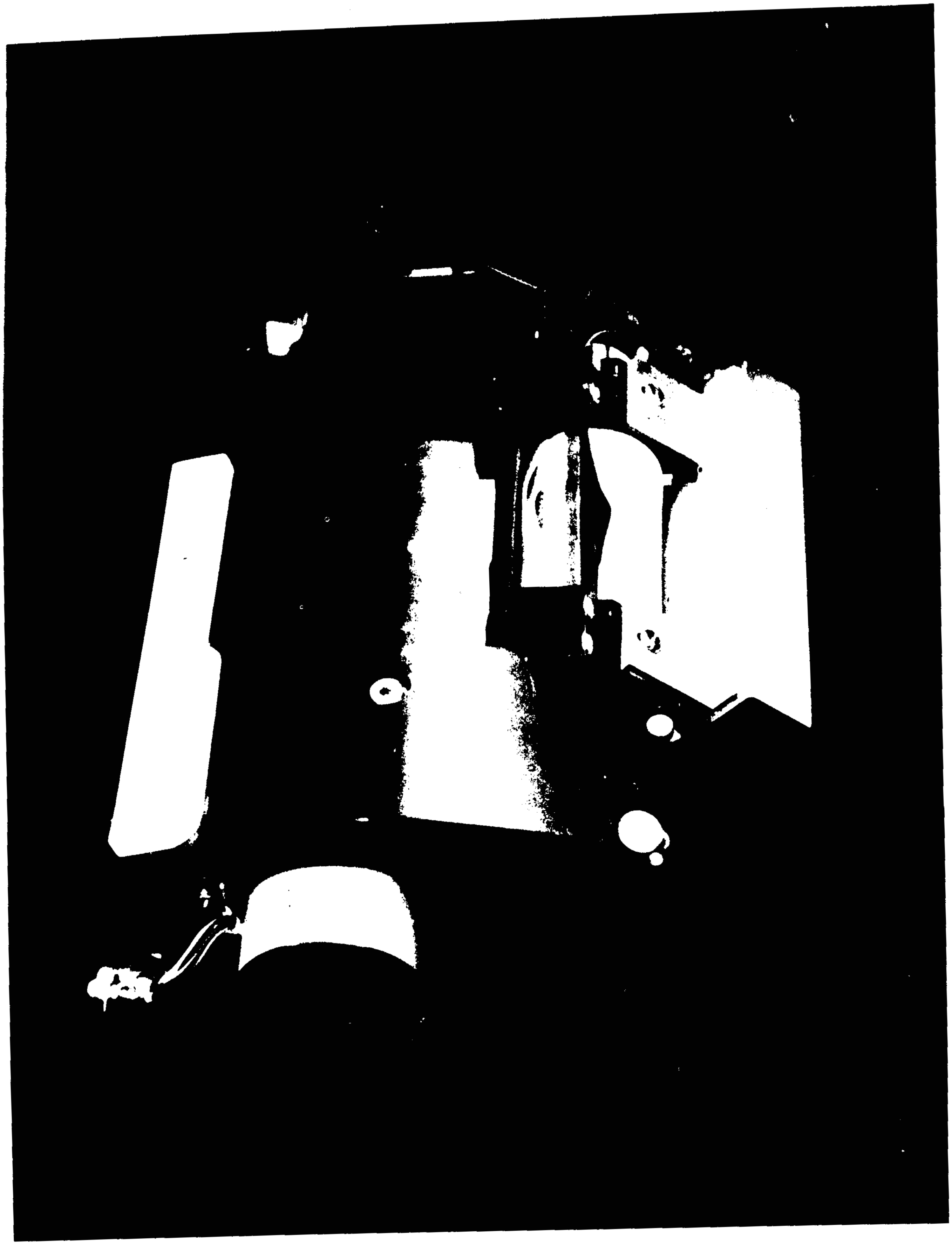
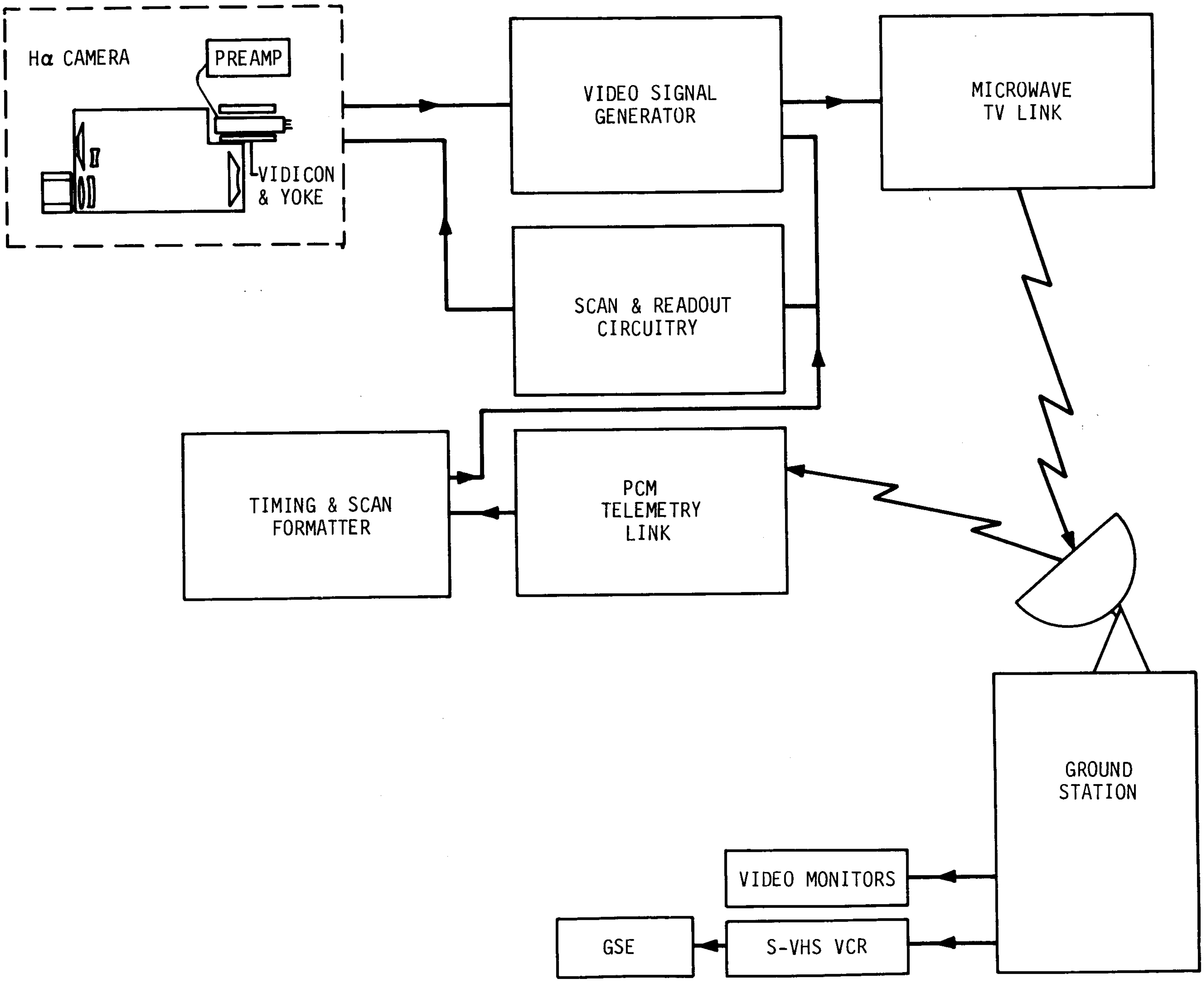


Figure 5

Functional block diagram of H-alpha/Vidicon electronics, with telemetry and command link to ground station.


Hα CAMERA
PREAMP
VIDICON & YOKE
VIDEO SIGNAL GENERATOR
MICROWAVE TV LINK
SCAN & READOUT CIRCUITRY
TIMING & SCAN FORMATTER
PCM TELEMETRY LINK
GROUND STATION
VIDEO MONITORS
GSE
S-VHS VCR

1. The x-ray multilayer telescope will be revised from Cassegrain to prime focus. This will result in 200X higher x-ray sensitivity at the focal plane if the same film is used as on the last flight, and a factor of 20 higher sensitivity if fine grain film is used for highest spatial resolution. We plan to use both types of film in this flight.

2. In addition to the H_α CCD camera system, which broadcasts real-time images during the flight, we are adding a high resolution intensified CCD XUV camera system, with a multilayer telescope tuned to 304 Å. The camera will record in-flight onto a Super-VHS recorder and also broadcast images to the ground; we will have the capability of controlling the image intensifier gain during the flight in order to optimize the signal. The telescope uses a new type of multilayer coating developed for this flight by T. W. Barbee, Jr. of LLNL.

In addition to the main NIXT telescope we are also adding an auxiliary system which will provide an image at 304 Å, which is dominated by the blended lines of He II and Si XI. Because these lines are so strong in the Solar spectrum, and because of the high reflectivity obtained, it is possible to use a 2.5 cm diameter mirror while still collecting enough photons to produce a real-time TV image. The picture format is 800X490 pixels, repeated every 1/30 second.

A useable image needs an average of 100 photons per pixel per frame, so that the required count rate is $\sim 10^9$ photons/second. We therefore need an effective collecting area of 1 cm^2 at 304 Å. The geometric collecting area of the mirror is ~6 cm^2 and we use a light-blocking filter of 1500 Å thick Aluminum evaporated onto the camera's focal plane. Taking into account the multilayer reflectivity and the Aluminum transmission at 304 Å our effective collecting area is 0.5 cm^2. A typical value of the He 304Å full Sun intensity is 4 X 10^9 photons-cm^{-2}-sec^{-1}, which implies that the image quality will be adequate.